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Database for the Tribological Properties of Self-Lubricating Materials

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TECHNICAL MEMORANDUM

DATABASE FOR THE TRIBOLOGICAL PROPERTIES OF SELF-LUBRICATING MATERIALS

1. INTRODUCTION

A test program was initiated to determine the tribological properties of several self-lubricating materials that have potential use in space applications. One potential application for these materials is as a self-lubricating cage in high-speed cryogenic bearings. An example of this application is the turbopump bearing in the space shuttle main engine (SSME) High-Pressure Oxygen Turbopump (HPOTP). Presently, these bearings use an Armalon (glass-reinforced polytetrafluorethylene) cage material. In this application, the intended lubrication mechanism is cage material transferred to the balls and raceways; however, this transferred material does not provide adequate lubrication. Also, glass fibers tend to be a source for high friction and heat generation. The purpose of this testing is to provide a database of tribological properties of various self-lubricating materials that may yield better results in such applications.

2. EXPERIMENTAL PROCEDURE

The self-lubricating materials that were tested, and their nominal compositions, are shown in table 1. These materials were tested using an LFW–1 Friction and Wear machine (block on ring tester). Our test configuration was a 440C stainless steel ring rotating against a block of the self-lubricating material. Surface velocity of the test ring was 7.9 m/min (26 ft/min), which is equivalent to a spindle speed of 72 r/min. The test ring was made of 440C stainless steel having a Rockwell hardness of 56 to 58 HRC. These rings had a ground face 8.15 mm wide with an outside diameter of 35 mm. The rings' surface finish was from 0.223 to 0.381 µm rms (9 to 15 µin rms) in the direction of motion. The test block was made of the self-lubricating material with a test surface 6.35 mm wide by 15.76 mm long.

Each material was tested at four loads (66 N, 133 N, 266 N, and 400 N), and three tests were performed at each load. Test duration was 69 min (4,968 cycles), and the coefficient of friction was continuously monitored and recorded by a data acquisition system during testing. Test specimens were weighed on an electronic analytic balance with a sensitivity to 0.00001 g before and after each test.

For a typical test, the specimens were ultrasonically cleaned in Freon and weighed. Next, the specimens were loaded into the tester, and the desired test load was applied to the test specimens through a dead weight loading mechanism. The machine was started and the ring rotated at 72 r/min for 69 min. After testing, the specimens were recleaned with Freon and weighed. The resulting mass loss was converted to a volumetric loss, and this was used to calculate the average test specimen wear rate for each testing.

3. TEST RESULTS AND DISCUSSION

Tables 2 through 11 and figures 1 through 8 summarize the coefficient of friction and the wear rates results from this testing. Tables 2 through 5 show the coefficient of friction results at the four test loads. These materials are ranked according to the average coefficient of friction for three tests. In figures 1 through 5 the coefficient of friction as function of the applied load for all test specimens is plotted. There was some variation in the relative ranking with load. Table 6 ranks the material over the entire load range. This ranking was obtained by averaging the ranking at the four load levels. The material with the lowest average coefficient was ranked first, and the one with the highest coefficient friction was ranked last. This table shows that the TFM material has the lowest coefficient friction. The carbon/PTFE composite, Chemloy 7589 (25 percent carbon graphite, 75 percent PTFE) and Delrin AF also performed well. In general, the polyimide-based materials had the highest coefficient of friction.

Tables 7 through 10 show the material rank based on the average wear rate at each test load. In figures 5 through 8, the wear rates of the self-lubricated test block as a function of applied load are plotted. The data are summarized and an overall ranking for lowest wear rate is shown in table 11. This table shows that the polyimide materials (Vespel SP211, Vespel SP21, and Vespel SP22) had the lowest wear rates. Chemloy 7570 (70 percent Bronze, 30 percent PTFE) also had a low wear rate. TFM and the carbon/PTFE composite had wear rates that were very high. These alloys should be used only in very low load applications. Chemloy 7574 (15 percent Cu, 85 percent PTFE) generated large amounts of wear debris. In addition, no copper transfer was observed to the 440C rings. These properties make them of limited use as self-lubricating materials.

Most self-lubricating materials that were tested appeared to generate good, adherent transfer film onto the 440C ring. Exceptions to this were the two copper/PTFE alloys, and the TFM materials. Optical inspection showed little, if any, evidence of a transfer film for these alloys. These alloys also generate large amounts of wear debris. The bronze/PTFE alloys appeared to generate the best transfer film. Their films are thick with uniform, adherent coatings of both PTFE and bronze.

When considering materials for LO_2 turbopump applications, the first criterion to consider is LO_2 compatibility. This criterion immediately rules out Delrin AF, Rulon-J, and Chemloy 7569 because they do not pass LO_2 impact testing. Four alloys—TFM, the carbon/PTFE composite, and the two Copper/PTFE alloys—can be eliminated from consideration due to excessively high wear rates. Cage or cage pocket inserts made from these alloys would quickly be worn away. The polyimide-based alloys can also be eliminated from consideration due to their high coefficients of friction. The remaining alloys would all have acceptable wear and friction properties. Of these, it is recommended to further evaluate the six bronze/PTFE alloys in the LO_2 traction tester to see if there is an optimum composition. It is also recommended to do further testing on Chemloy 7558 and Chemloy 7520 since both alloys yielded a compromise of intermediate wear rate and coefficient of friction results.

4. CONCLUSIONS

Test results led to the following conclusions:

- TFM (100 percent PTFE) composite yielded the lowest coefficient of all alloys tested.
- The polyimide-based alloys had the highest coefficients of friction, but these alloys yielded the lowest wear rates.
- TFM and the carbon/PTFE alloys had very high wear rates and probably should only be used in low load applications.
- The copper/PTFE-based alloys produced copious amounts of wear debris with little, if any, transfer film.
- The bronze/PTFE-based alloys were the best overall performers and produce very adherent transfer films.

Table 1. Trade names. Nominal compositions and manufacturer of self-lubricating materials.

Material	Composition	Manufacturer
TFM	100% PTFE	John Crane
Carbon/PTFE Composite	100% PTFE Matrix With Carbon Fibers	NASA
Rulon-J	Reinforce PTFE Compound	Dixon
Delrin AF	Acetal Resin With Fluorocarbon Fibers	DuPont
Chemloy 7558	25% Graphite, 75% PTFE	John Crane
Chemloy 7589	25% Carbon Graphite, 75% PTFE	John Crane
Chemloy 7519	60% Bronze, 40% PTFE	John Crane
Chemloy 7575	25% Copper, 75% PTFE	John Crane
Chemloy 7569	40% Bronze, 60% PTFE	John Crane
Chemloy 7584	40% Bronze, 5% MoS_2, 55% PTFE	John Crane
Chemloy 7520	25% Carbon, 75% PTFE	John Crane
Chemloy 7568	30% Bronze, 70% PTFE	John Crane
Chemloy Q18	50% Bronze, 50% PTFE	John Crane
Chemloy 7574	15% Copper, 85% PTFE	John Crane
Chemloy 7570	70% Bronze, 30% PTFE	John Crane
Chemloy 7586	55% Bronze, 5% MoS_2, 40% PTFE	John Crane
Vespel SP3	15% MoS_2, 85% Polymide	DuPont
Vespel SP22	40% Graphite, 60% Polyimide	DuPont
Vespel SP21	15% Graphite, 85% Polyimide	DuPont
Vespel SP211	15% Graphite, 85% Polyimide	DuPont

Table 2. Average coefficient of friction at 66 N normal load and 7.9 m/min.

TFM	0.12	Chemloy 7584	0.19
Chemloy 7586	0.12	Chemloy 7520	0.19
Rulon-J	0.16	Vespel SP3	0.20
Chemloy Q18	0.17	Chemloy 7574	0.20
Chemloy 7558	0.17	Chemloy 7570	0.22
Chemloy 7589	0.17	Vespel SP211	0.23
Chemloy 7579	0.18	Chemloy 7569	0.24
Chemloy 7519	0.18	Vespel SP22	0.32
Chemloy 7575	0.18	Vespel SP21	0.35
Delrin	0.19	Carbon/PTFE Composite	No Test Due to Limited Number of Test Specimens

Table 3. Average coefficient of friction at 133 N normal load and 7.9 m/min relative velocity.

Carbon/PTFE Composite	0.11	Chemloy 7558	0.17
Chemloy 7586	0.12	Chemloy 7575	0.18
TFM	0.12	Chemloy 7520	0.18
Delrin	0.14	Chemloy 7574	0.19
Rulon-J	0.14	Chemloy 7519	0.21
Chemloy 7589	0.15	Vespel SP3	0.22
Chemloy Q18	0.16	Vespel SP211	0.23
Chemloy 7568	0.16	Chemloy 7569	0.26
Chemloy 7579	0.17	Vespel SP22	0.34
Chemloy 7570	0.17	Vespel SP21	0.47
Chemloy 7584	0.17		

Table 4. Average coefficient of friction at 266 N normal load and 7.9 m/min relative velocity.

Chemloy 7589	0.10	Chemloy 7574	0.17
Delrin	0.11	Chemloy 7570	0.21
Chemloy 7575	0.12	Chemloy 7519	0.22
Carbon/PTFE Composite	0.13	Chemloy 7586	0.24
Teflon/TFM	0.13	Chemloy 7569	0.26
Chemloy 7568	0.14	Vespel SP3	0.27
Rulon-J	0.14	Vespel SP211	0.28
Chemloy 7579	0.15	Vespel SP22	0.36
Chemloy 7558	0.16	Vespel SP21	0.45
Chemloy Q18	0.16		

Table 5. Average coefficient of friction at 400 N normal load and 7.9 m/min relative velocity.

Chemloy 7575	0.07	Chemloy 7579	0.17
TFM	0.07	Chemloy Q18	0.17
Carbon/PTFE Composite	0.09	Chemloy 7586	0.21
Chemloy 7589	0.11	Chemloy 7519	0.21
Delrin	0.11	Chemloy 7568	0.21
Rulon-J	0.14	Vespel SP3	0.24
Chemloy 7570	0.14	Chemloy 7569	0.24
Chemloy 7574	0.15	Vespel SP211	0.25
Chemloy 7558	0.15	Vespel SP22	0.35
Chemloy 7584	0.17	Vespel SP21	0.50
Chemloy 7520	0.17		

Table 6. Overall ranking of self-lubricating materials based on coefficient of friction.

TFM	Chemloy 7584
Carbon/PTFE Composite	Chemloy 7570
Chemloy 7589	Chemloy 7520
Rulon-J	Chemloy 7574
Delrin	Chemloy 7519
Chemloy 7575	Vespel SP3
Chemloy 7558	Chemloy 7569
Chemloy Q18	Vespel SP211
Chemloy 7586	Vespel SP22
Chemloy 7579	Vespel SP21
Chemloy 7568	

Table 7. Average wear rate at 66 N normal load and 7.9 m/min relative velocity.

Chemloy 7570	2.0E–7	Delrin	2.0E–6
Vespel SP211	4.6E–7	Chemloy 7589	2.4E–6
Chemloy 7558	6.3E–7	Chemloy 7579	3.9E–6
Vespel SP21	8.9E–7	Chemloy 7568	5.3E–6
Chemloy 7586	1.0E–6	Chemloy 7519	5.4E–6
Chemloy 7569	1.0E–6	Chemloy 7584	1.5E–5
Chemloy 7520	1.1E–6	Chemloy 7574	6.0E–5
Rulon-J	1.3E–6	Chemloy 7575	7.4E–5
Vespel SP22	1.4E–6	TFM	1.1E–4
Chemloy Q18	1.9E–6	Carbon/PTFE Composite	No Test Due to the Limited Number of Test Specimens

Table 8. Average wear rate at 133 N normal load and 7.9 m/min relative velocity.

Vespel SP211	6.5E–7	Chemloy 7586	3.2E–6
Vespel SP22	7.0E–7	Chemloy Q18	3.2E–6
Chemloy 7569	1.2E–6	Chemloy 7568	7.4E–6
Chemloy 7520	1.5E–6	Chemloy 7579	7.6E–6
Rulon-J	1.5E–6	Carbon/PTFE Composite	1.4E–5
Chemloy 7589	1.7E–6	Chemloy 7519	2.0E–5
Vespel SP3	1.9E–6	Chemloy 7584	3.1E–5
Vespel SP21	1.9E–6	Chemloy 7574	1.3E–4
Chemloy 7570	2.4E–6	Chemloy 7575	2.2E–4
Chemloy 7558	2.7E–6	TFM	2.9E–4
Delrin	2.8E–6		

Table 9. Average wear rate at 266 N normal load and 7.9 m/min relative velocity.

Vespel SP211	1.1E–6	Chemloy 7520	4.8E–6
Delrin	1.2E–6	Chemloy 7568	9.5E–6
Chemloy 7570	1.2E–6	Chemloy 7586	1.6E–6
Chemloy Q18	1.3E–6	Chemloy 7579	2.6E–5
Chemloy 7569	1.7E–6	Chemloy 7519	2.7E–5
Vespel SP22	2.1E–6	Carbon/PTFE Composite	2.7E–5
Vespel SP21	2.3E–6	Chemloy 7584	7.1E–5
Rulon-J	2.8E–6	Chemloy 7574	2.5E–4
Chemloy 7558	3.7E–6	Chemloy 7575	3.1E–4
Chemloy 7589	3.9E–6	TFM	3.7E–4

Table 10. Average wear rate at 400 N and 7.9 m/min relative velocity.

Vespel SP211	4.7E–E	Chemloy 7558	1.1E–5
Vespel SP21	1.5E–6	Chemloy Q18	1.9E–5
Delrin	2.5E–6	Chemloy 7568	2.9E–5
Rulon-J	3.2E–6	Chemloy 7519	3.6E–5
Chemloy 7570	3.5E–6	Chemloy 7579	4.5E–5
Vespel SP22	4.2E–6	Chemloy 7586	1.4E–4
Vespel SP3	4.3E–6	Chemloy 7584	1.5E–4
Chemloy 7520	5.0E–6	Chemloy 7575	3.5E–4
Chemloy 7569	5.7E–6	TFM	5.5E–4
Chemloy 7589	1.0E–5	Carbon/PTFE Composite	1.6E–3

Table 11. Overall ranking of self-lubricating materials based on lowest wear rate.

Vespel SP211	Chemloy Q18
Vespel SP21	Chemloy 7568
Chemloy 7570	Chemloy 7579
Vespel SP22	Chemloy 7519
Delrin	Chemloy 7586
Rulon-J	Chemloy 7584
Chemloy 7569	Chemloy 7574
Vespel SP3	Chemloy 7575
Chemloy 7520	TFM
Chemloy 7589	Carbon/PTFE
Chemloy 7558	

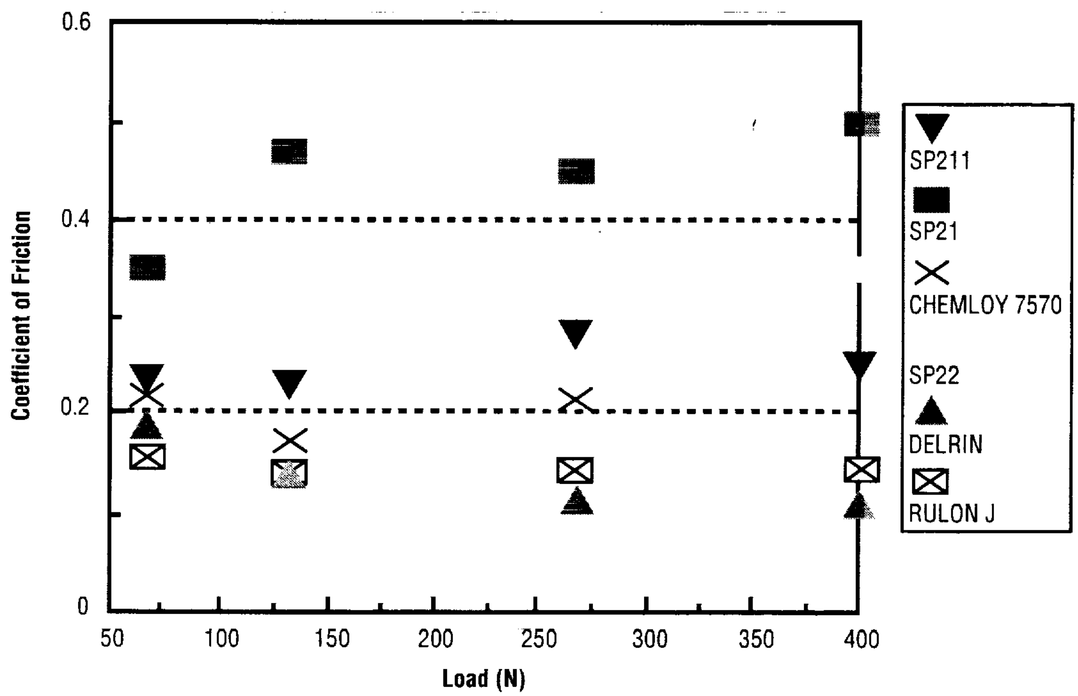

Figure 1. Coefficient of friction as a function of load.

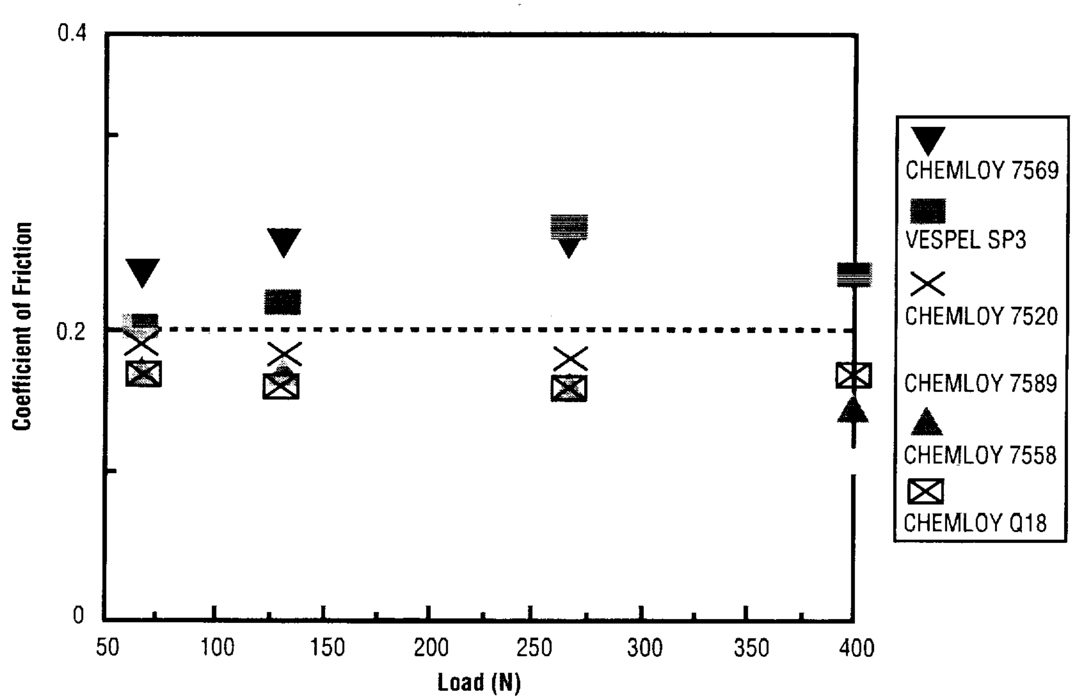

Figure 2. Coefficient of friction as a function of load.

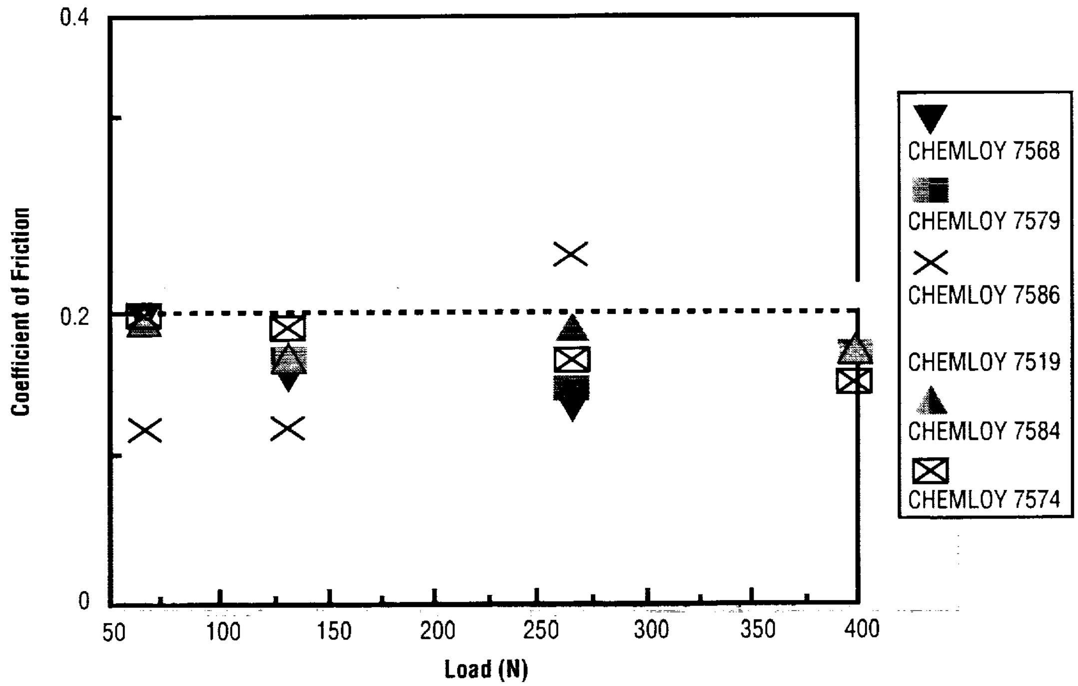

Figure 3. Coefficient of friction as a function of load.

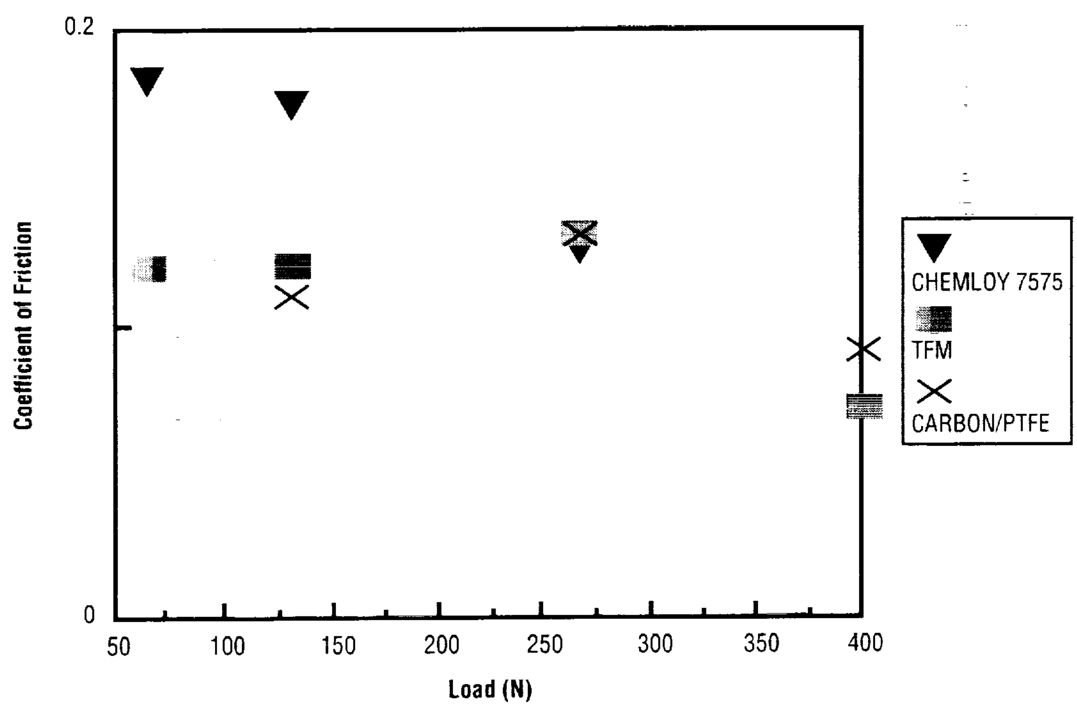

Figure 4. Coefficient of friction as a function of load.

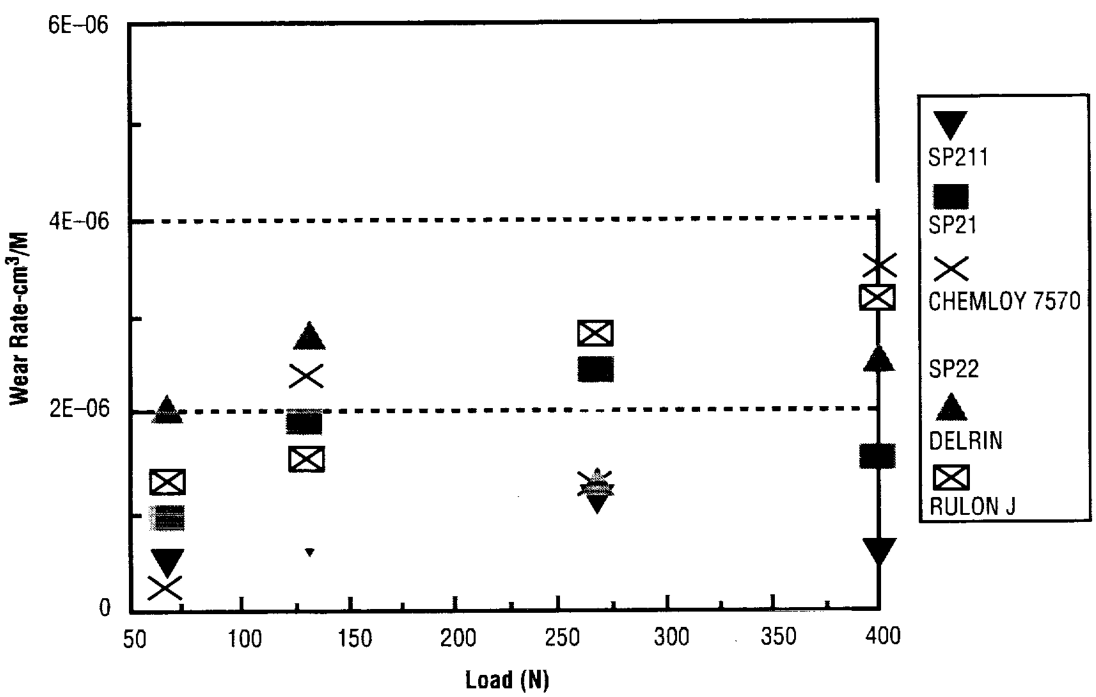

Figure 5. Wear rate as a function of load.

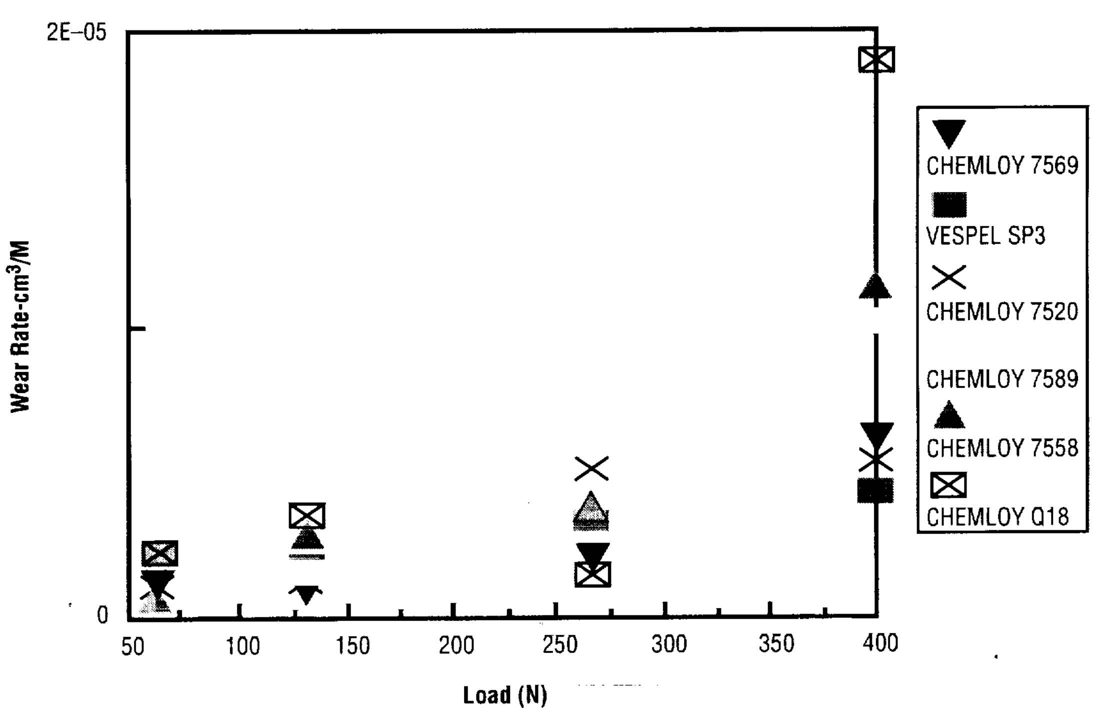

Figure 6. Wear rate as a function of load.

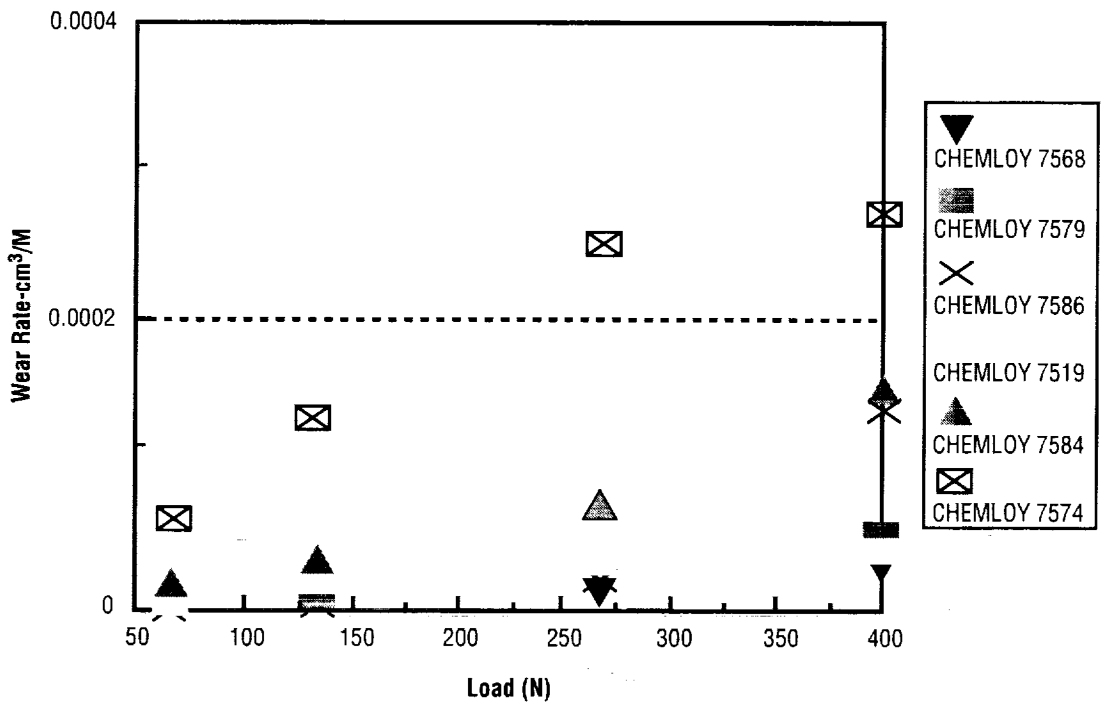

Figure 7. Wear rate as a function of load.

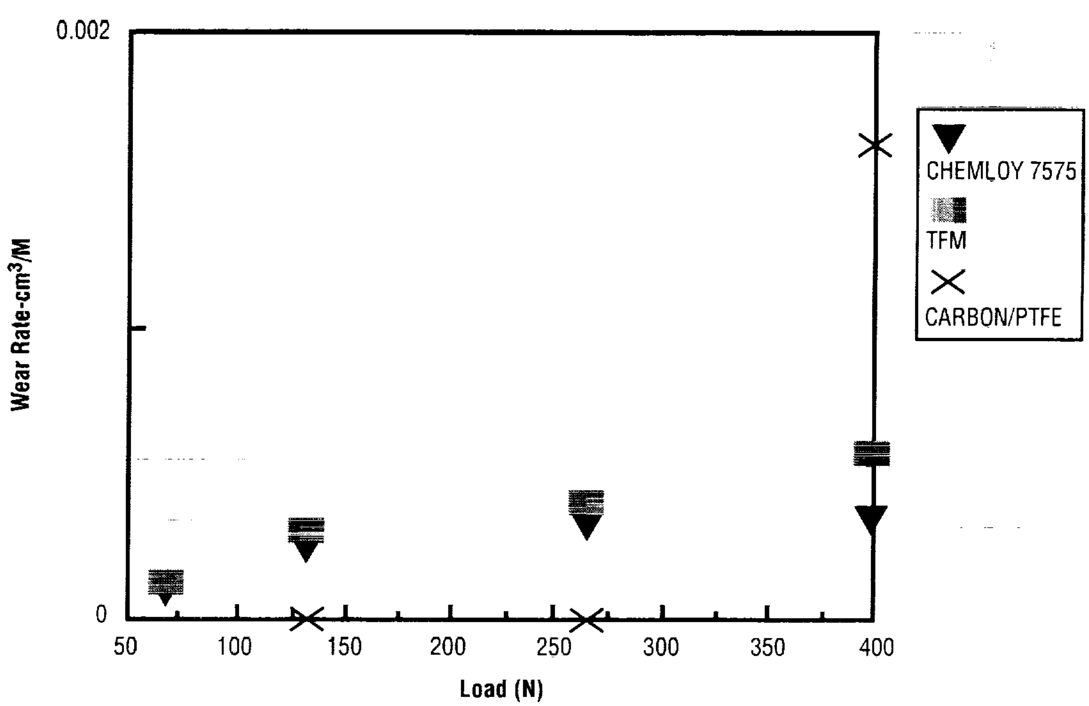

Figure 8. Wear rate as a function of load.

APPROVAL

DATABASE FOR THE TRIBOLOGICAL PROPERTIES OF SELF-LUBRICATING MATERIALS

T.R. Jett and R.L. Thom

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

A.F. Whitaker

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13. ABSTRACT *(Maximum 200 words)*

A test program to determine the tribological properties of several self-lubricating composites was performed. Testing was done using an LFW–1 Friction and Wear machine. Each material was tested at four load levels (66 N, 133 N, 266 N, and 400 N) under ambient conditions. The coefficient of friction and wear rate was determined for each material, and a relative ranking of the composites was made.

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